A Modeling Approach for Methane Capture Performance and Strategy from Abandoned Coal Mines

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Introduction

- Abandoned coal mines in the U.S. as of 2002*
  - 7582 mines in major coal basins
  - 393 mines with >2860 m^3/day

244 known status

Vented | Flooded | Sealed

- Recovering methane from sealed mines can help utilizing an unconventional source

* Source: US EPA 430-R-04-001

Introduction

Shafts and drifts can be plugged with concrete

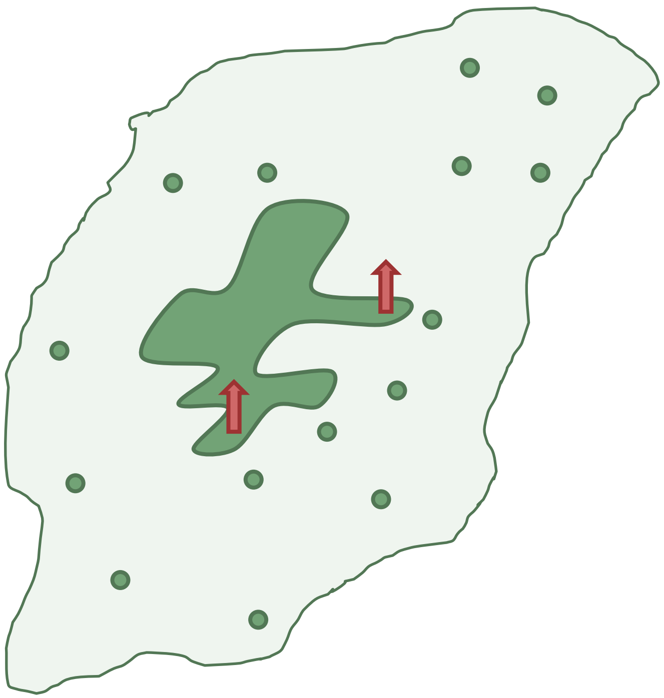
Sections of the mine are isolated using mine seals

- Sealed mines act as composite methane reservoirs
  - Using reservoir evaluation and modeling techniques can help
    - Managing methane extraction potential
    - Forecasting
    - Understanding seal leakage and gas emission from coal

Technical issues

- Requires key reservoir properties
  - Properties of coal and mine environment need to be estimated
- Coal properties show spatial variability
  - Spatial continuity should be defined and used
- Complex geometry
  - Mine boundaries and structures need to be defined with sufficient detail
- Initial conditions
  - Initial conditions at the time of mine closure and the time of analysis start need to be defined

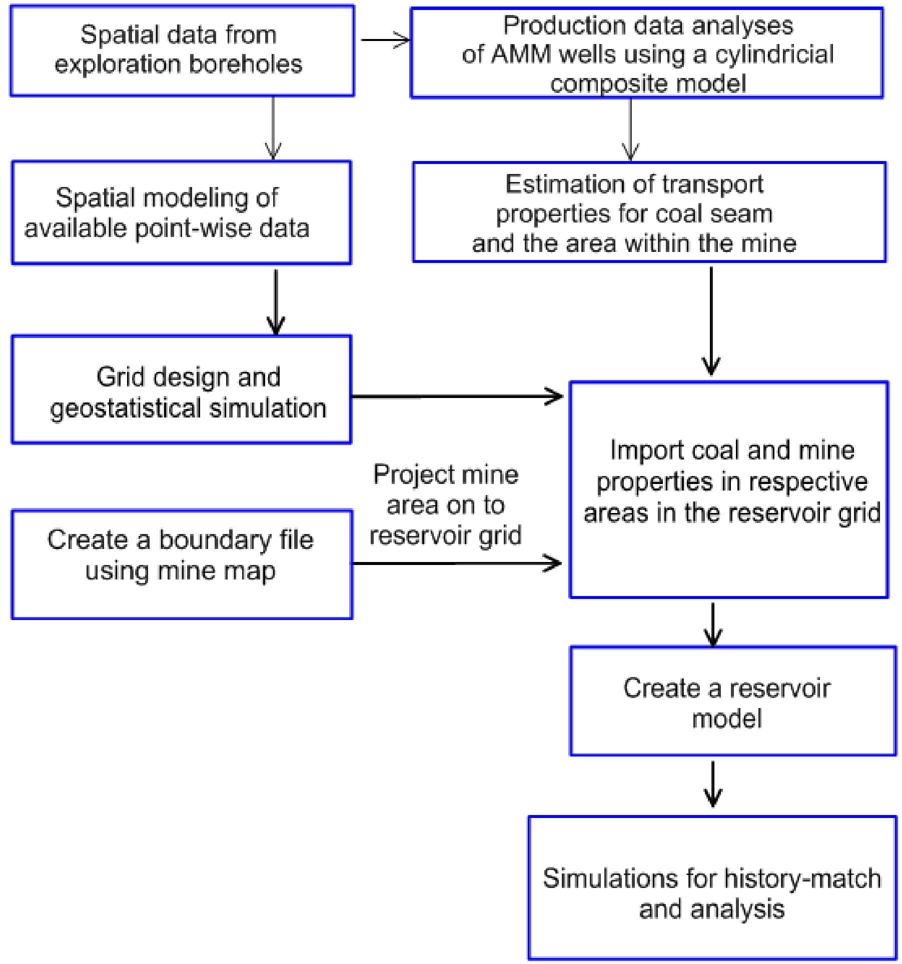
Methodology



Exploration borehole (spatial data)

AMM production borehole

Mine area



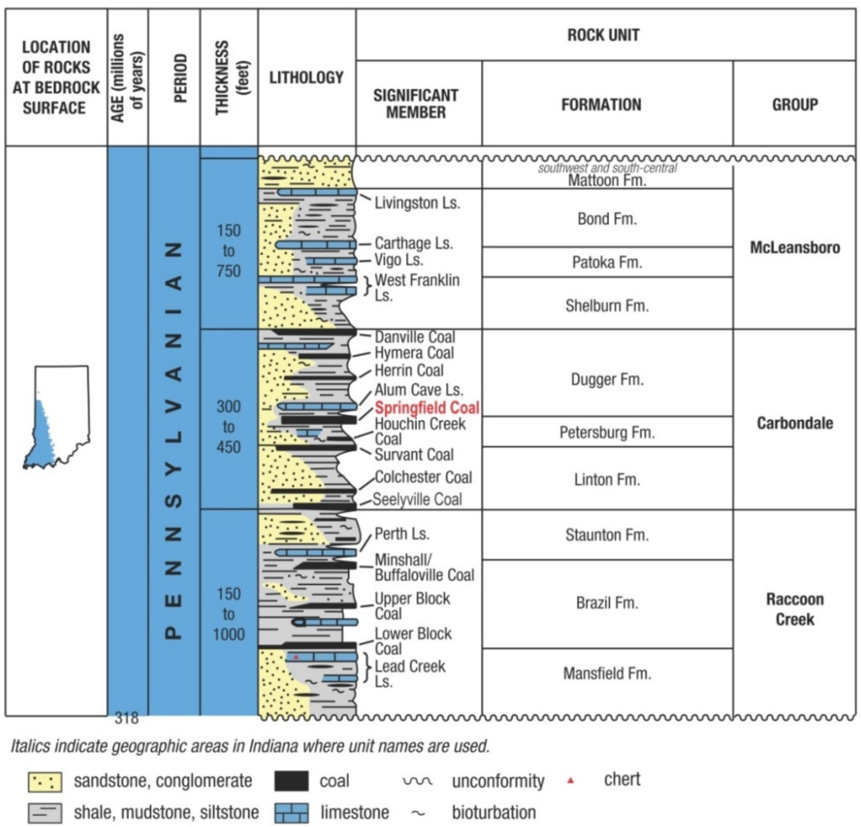
Demonstration with a case study

- Indana section of the Illinois basin

- Buck Creek mine
  - Room and pillar mine
  - Operated in Springfield coal seam
  - Produced 0.3 million tons of coal and an estimated 11500 m^3/day emission from ventilation system in 1995
  - Abandoned in 1996
  - AMM has been produced since 2007 by wells drilled in 2 sealed sections

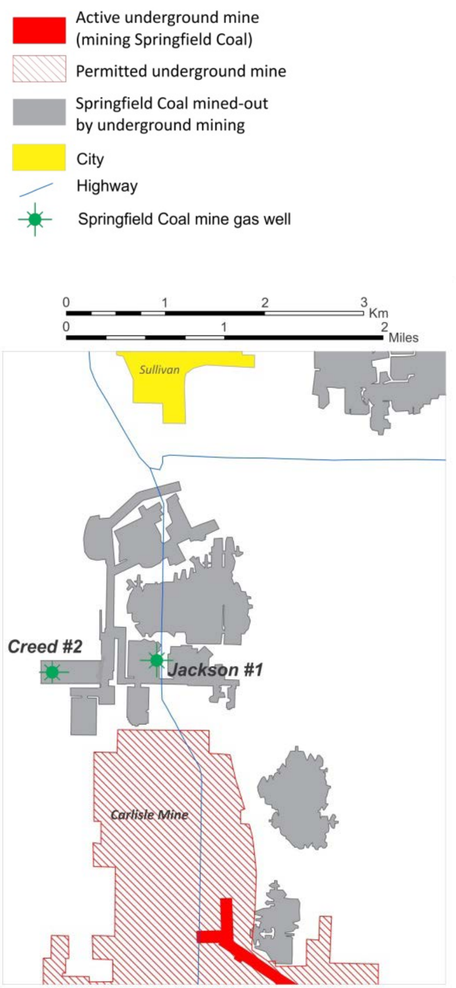
Location of study site and coal seam

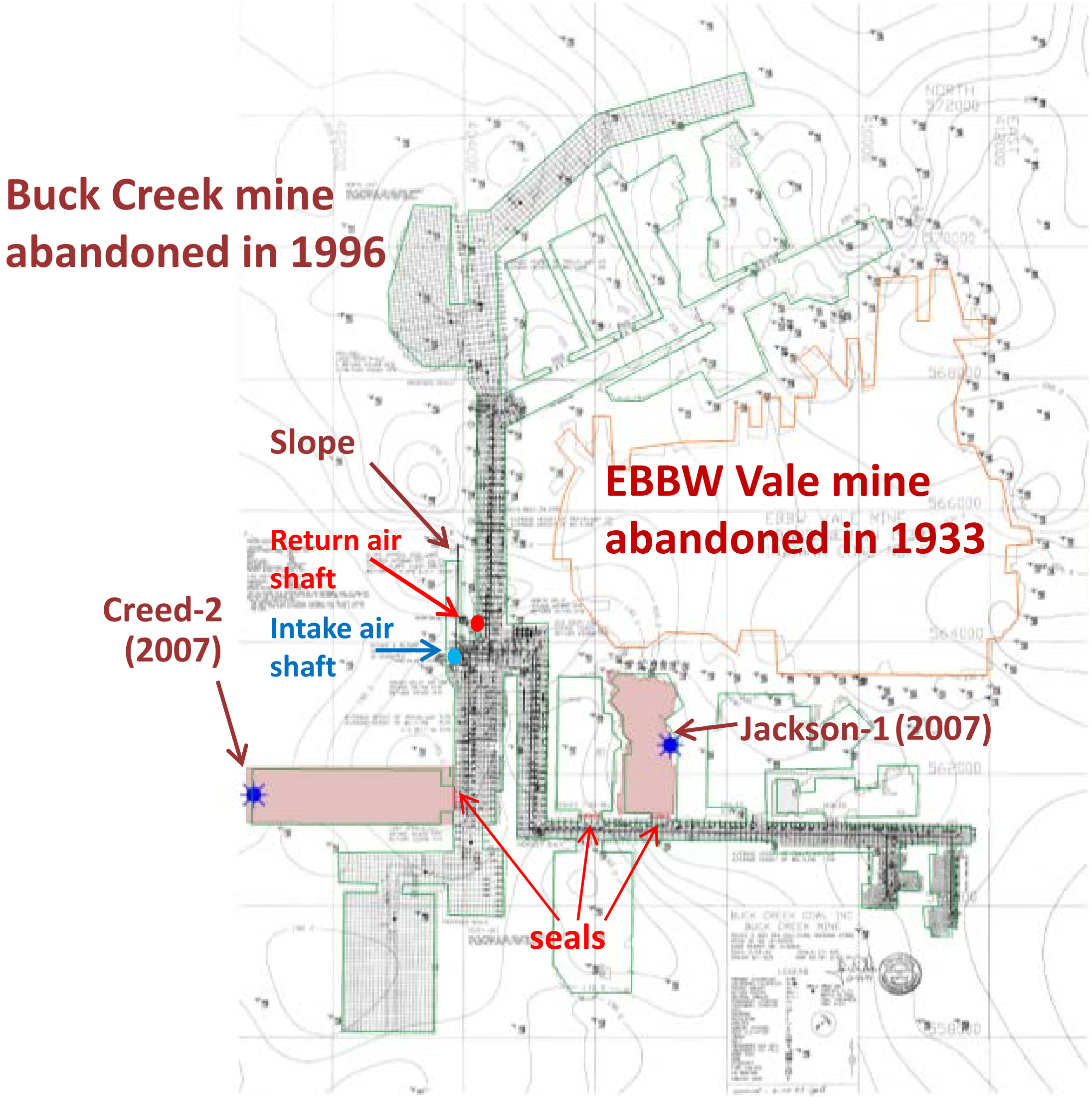
- Sullivan County, IN
- Springfield coal seam



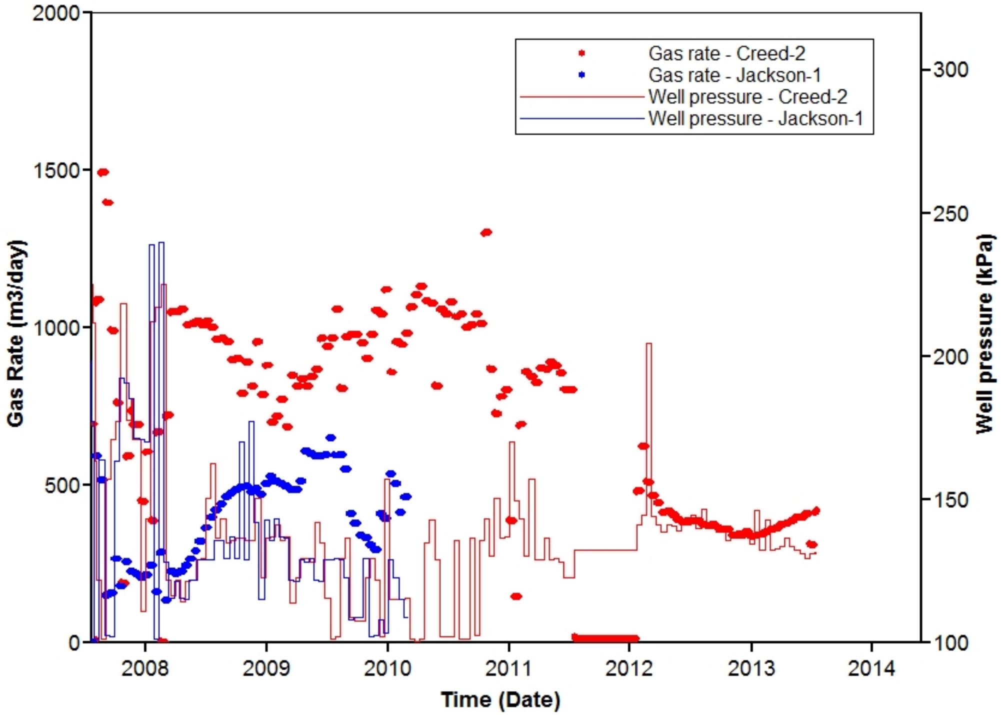
Moisture (wt %)	10.1
Ash yield (wt %)	5.3
Volatile matter (wt %)	40.5
Fixed carbon (wt %)	44.1
Carbon (wt %)	70.4
Hydrogen (wt %)	4.9
Nitrogen (wt %)	1.4
Oxygen (wt %)	6.9
Vitrinite (vol %)	73.4
Liptinite (vol %)	6.4
Inertinite (vol %)	15.4
Mineral matter (vol %)	4.8
Ro (%)	0.63

Mines within the study area





Historical production and pressure data

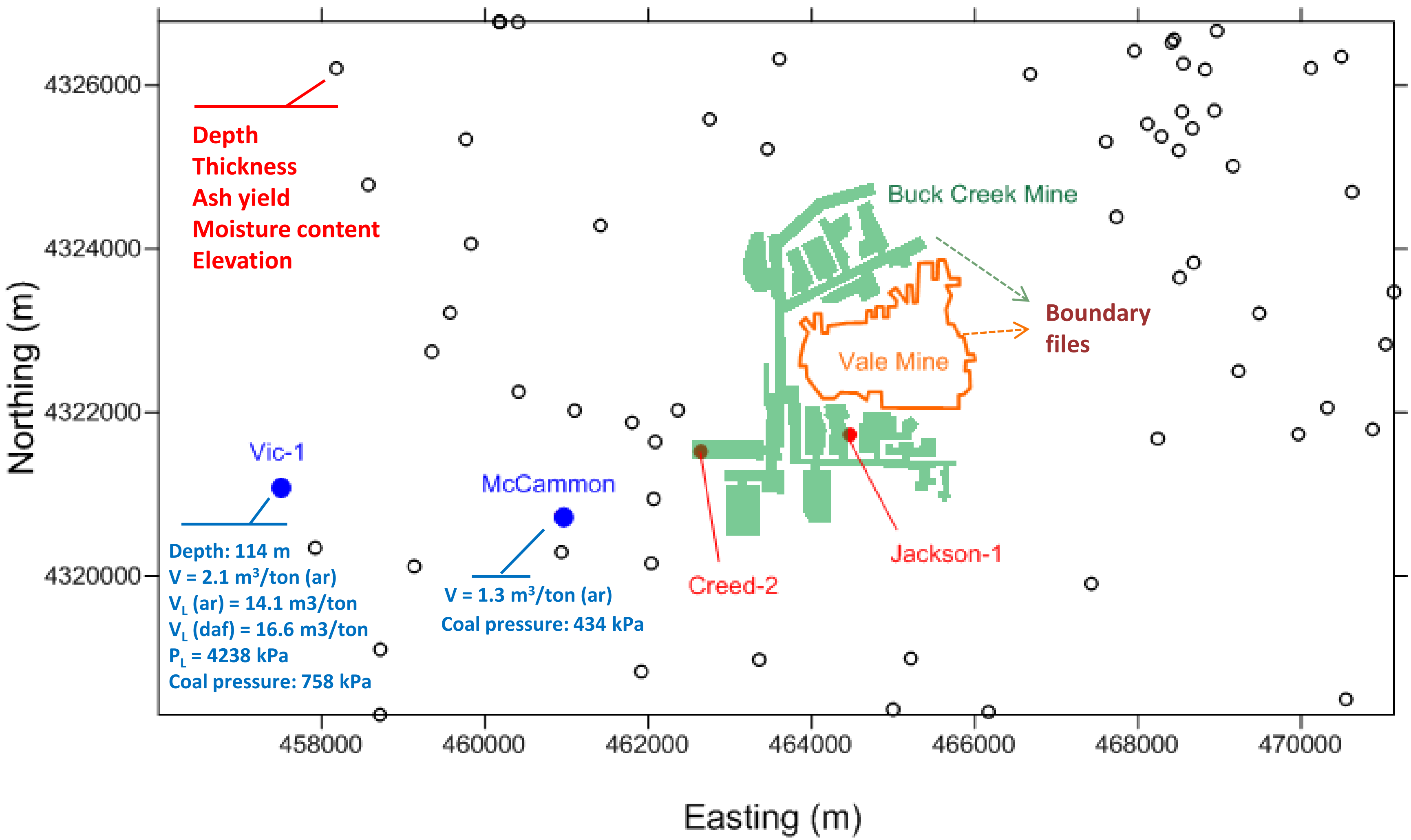


- Start of production: July, 2007
- Cumulative production as of July 2013:

Creed-2: 1.9×10^6 m^3 gas
Jackson-1: 0.6×10^6 m^3 gas

Well	Gas concentration (%)				
	Methane	Ethane	Propane	CO_2	N_2
Creed-2	96.33	0.09	0	1.47	2.11
Jackson-1	96.39	0.02	0	1.48	2.11

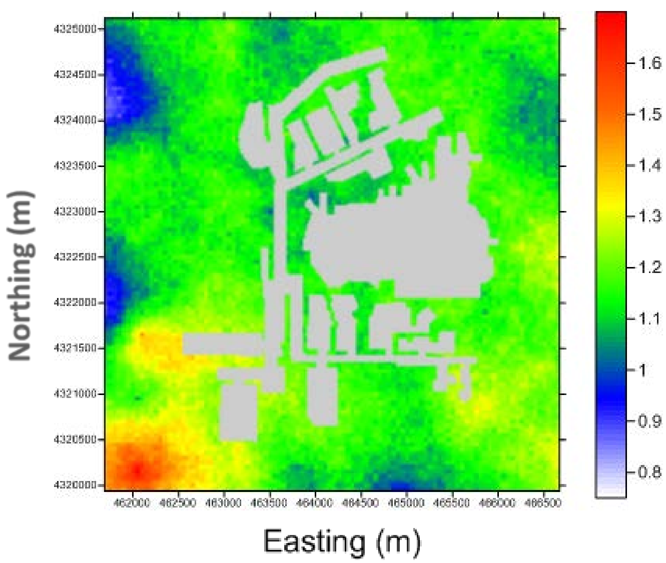
Point-wise spatial data



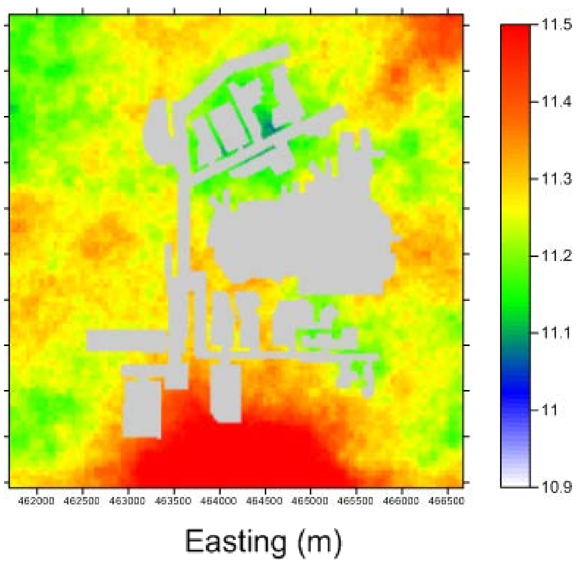
Spatial continuity of point-wise data

- Semi-variogram modeling
- Geostatistical simulation grid ⟺ reservoir simulation grid
- Sequential Gaussian simulation (100 realizations)

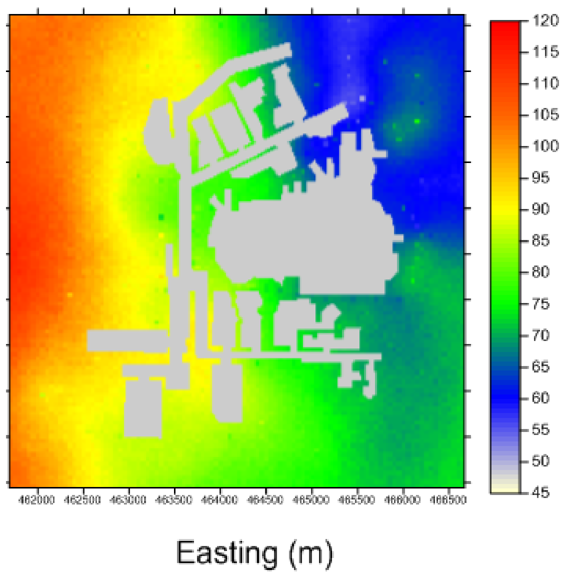
E-type coal thickness (m)



E-type Langmuir volume (m^3/ton)

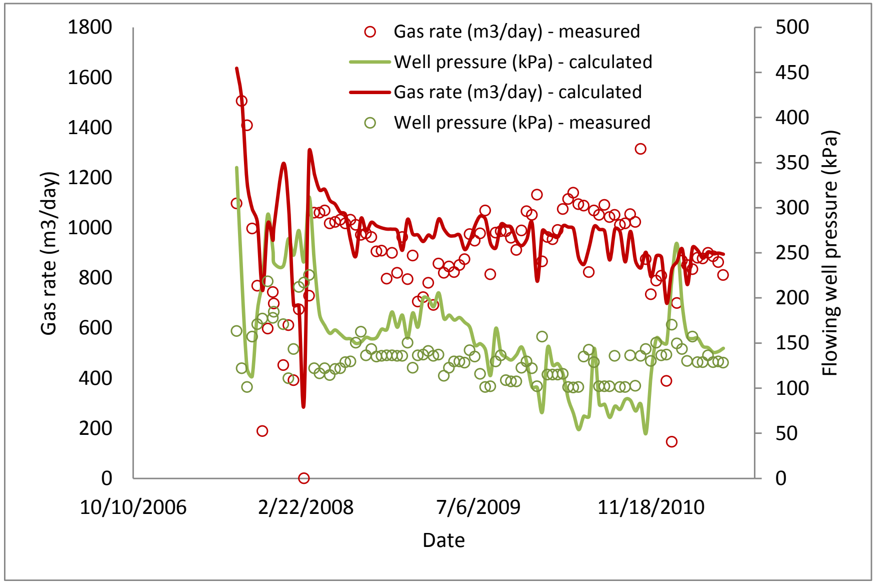


E-type coal depth (m)



Mine properties and estimation of initial conditions of 2007

- A cylindrical composite model with two zones (mine workings +coal) was used
- Mine map was used to fix some of the properties (i.e. Ø, s_f)
- Production data and flowing well pressures were matched to estimate initial pressure and properties of zones



Initial pressure (kPa) - 2007	345
Permeability of mine area (md)	15000
Permeability of coal (md)	55
Porosity of mine area (%)	30
Porosity of coal (%)	3

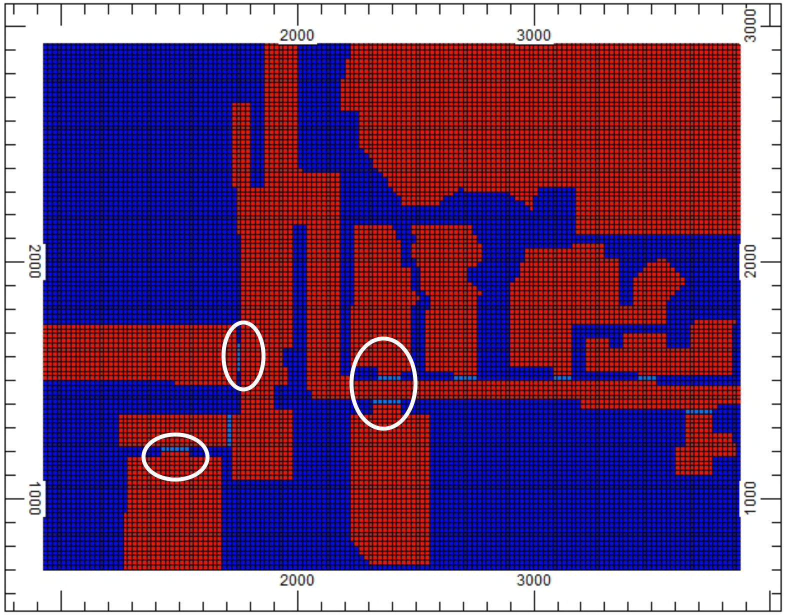
Permeability of mine area	isotropic
Permeability of coal - y	11

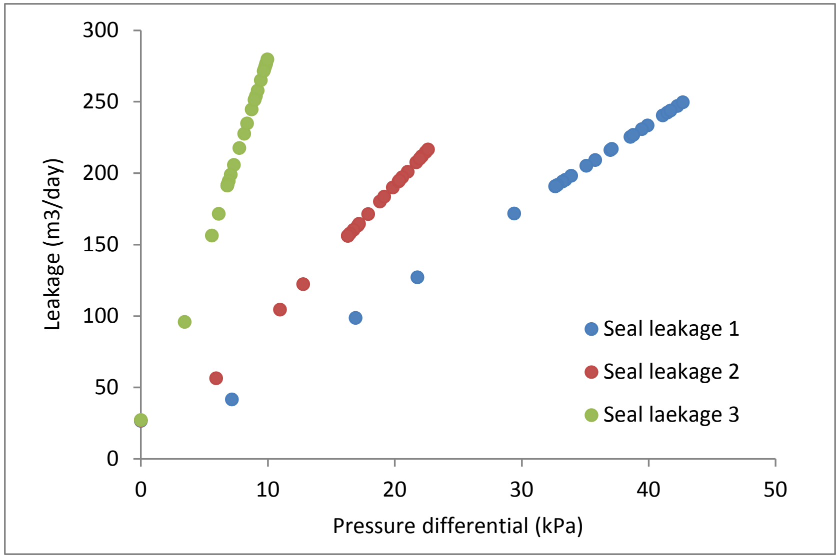
S_f coal (x, y) - mm	8.4, 4.5
S_f of mine area (x, y) -m	14, 29

Reservoir simulation model

- Built by assigning spatial maps (E-type from SGSim), and uniform coal and mine properties (from composite model) within relevant boundaries

- Seals shown in the mine map were represented by grids with different leakage characteristics in history matching

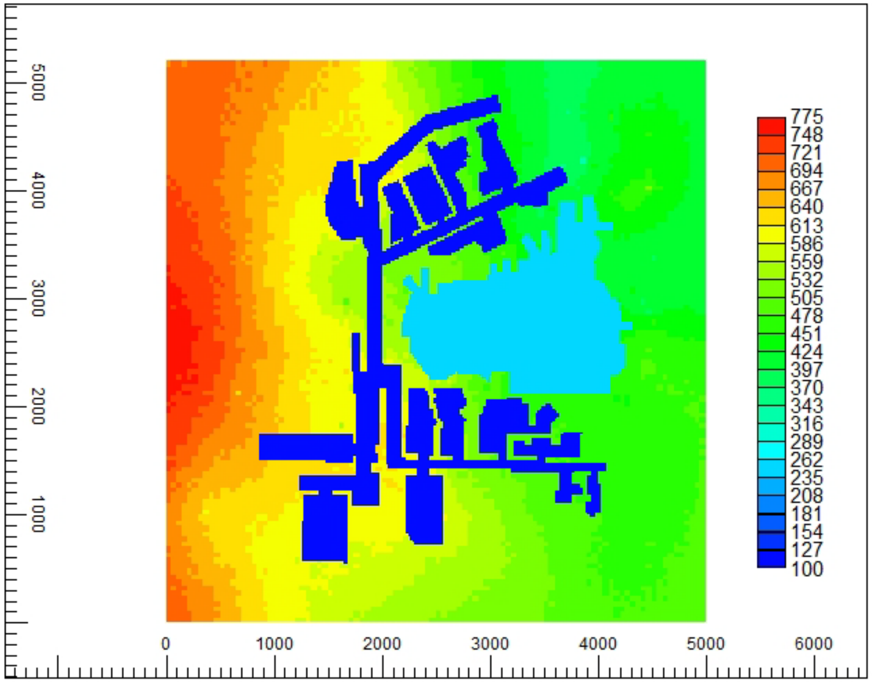




Reservoir simulation model

- Coal seam was initialized at 1996 using Vic-1's pressure gradient
- Buck Creek mine was initialized with 100 kPa in 1996
- Vale was initialized with the equilibrium pressure (275 kPa)

Pressure distribution – 1996 – when mine was closed

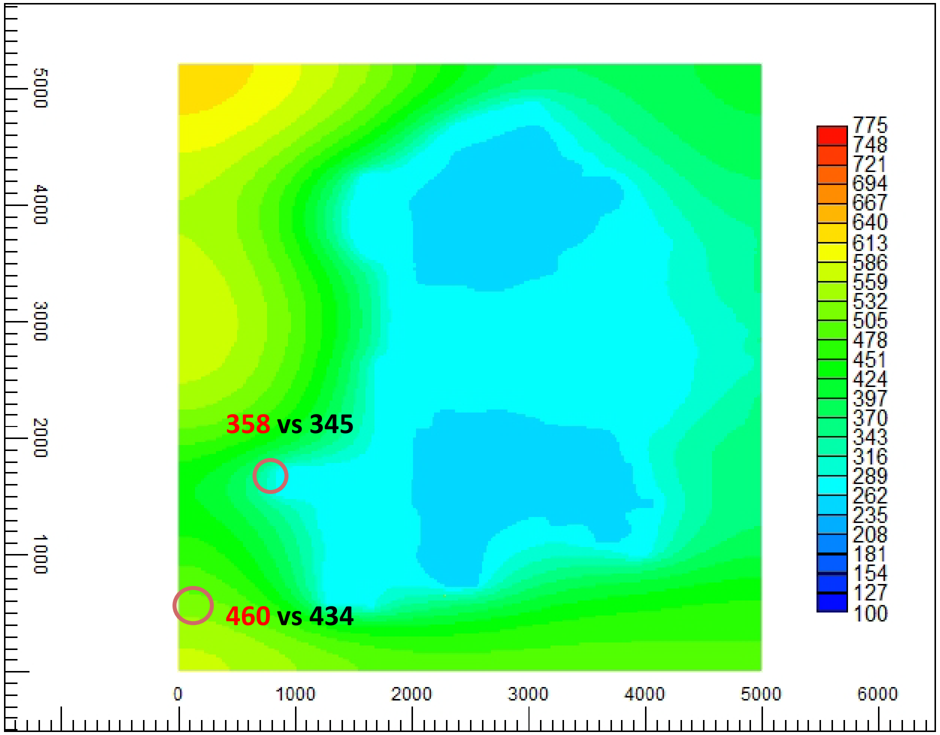


Reservoir simulation model

- Run until 2007 for coal and mine area to attain their initial conditions at the start of history match

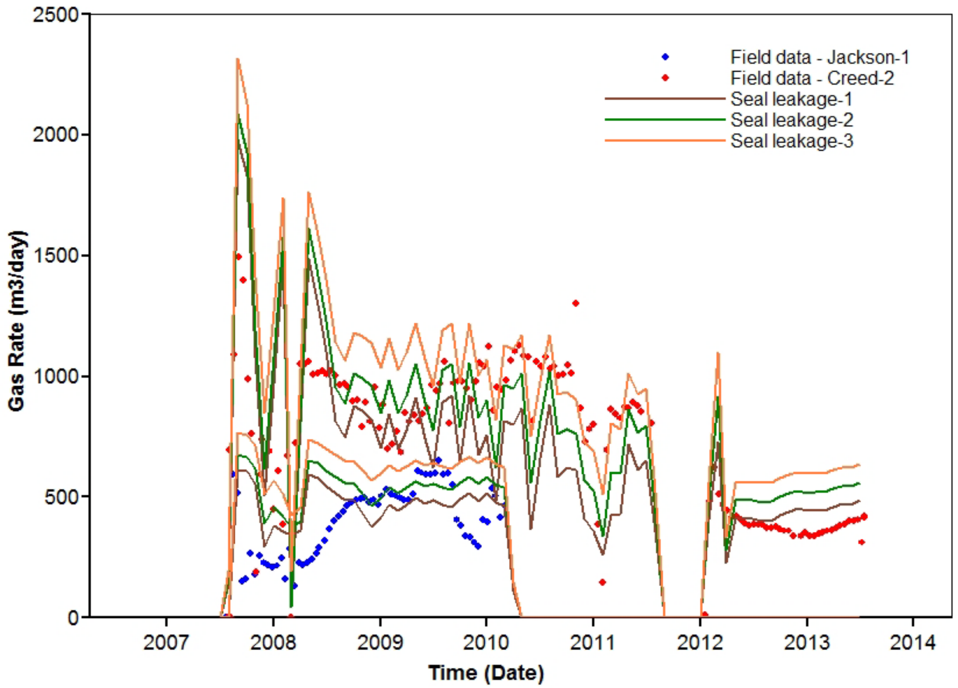
- Pressures at McCammon and Creed-2 locations were checked

Pressure distribution – July, 2007 – Just before wells start production



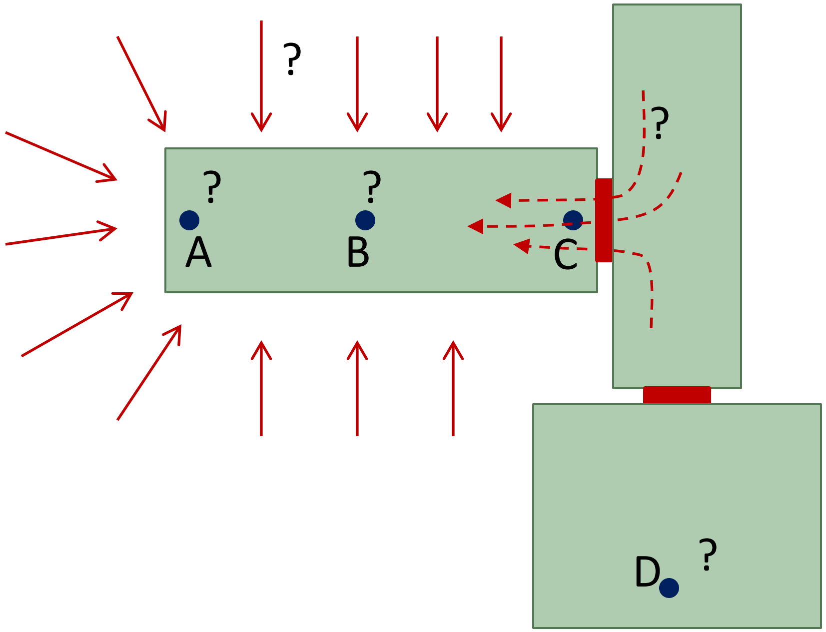
Production history match

- History match work was started with the conditions of 2007
- Wells (Creed-2 and Jackson-1) were "drilled" in July 2007 and operated with flowing BHP conditions until July 2013.
- Three seal leakages were implemented for history match
- Seal leakage-2 provided the best match for both wells



Results

- History match is often not the ultimate goal of a modeling study
  - Flow paths of the captured gas
  - Well placement within the sealed section
  - Contribution from different sources
  - Selection of alternate sealed areas



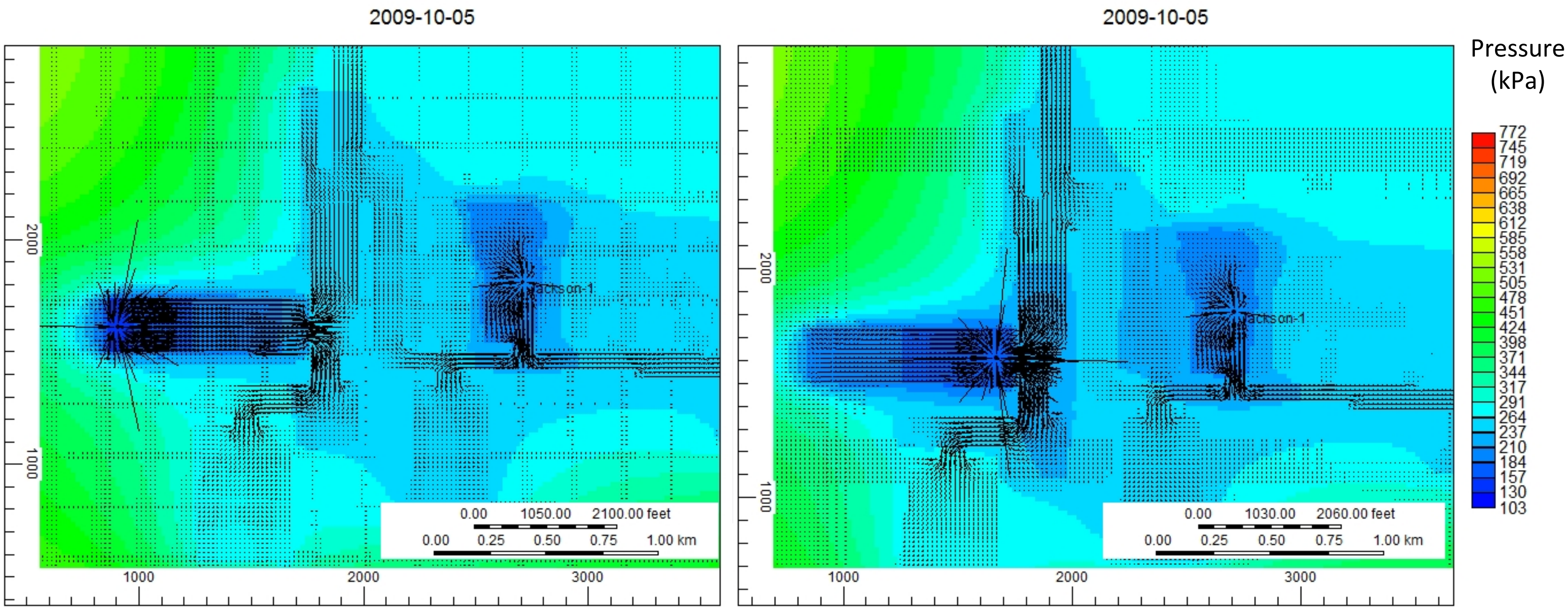
Results

- Gas flow paths into the sealed area

- Accumulated gas in the seal area, gas emission from coal and gas leaking from seals all contribute to captured gas

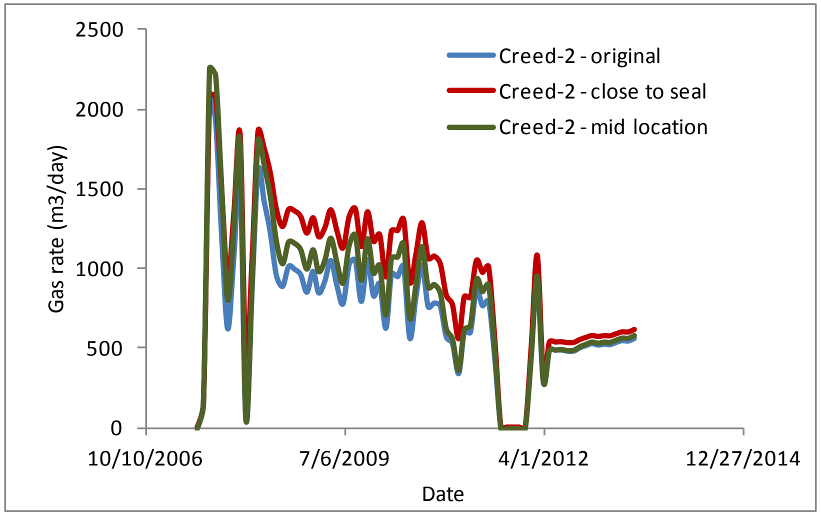
Creed-2 at its original location

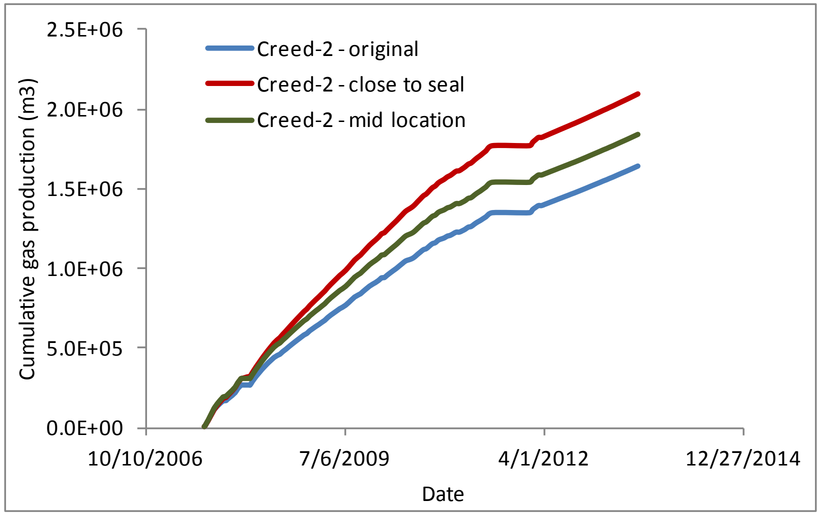
Creed-2 close to seal



Results

- Methane capture from Creed-2





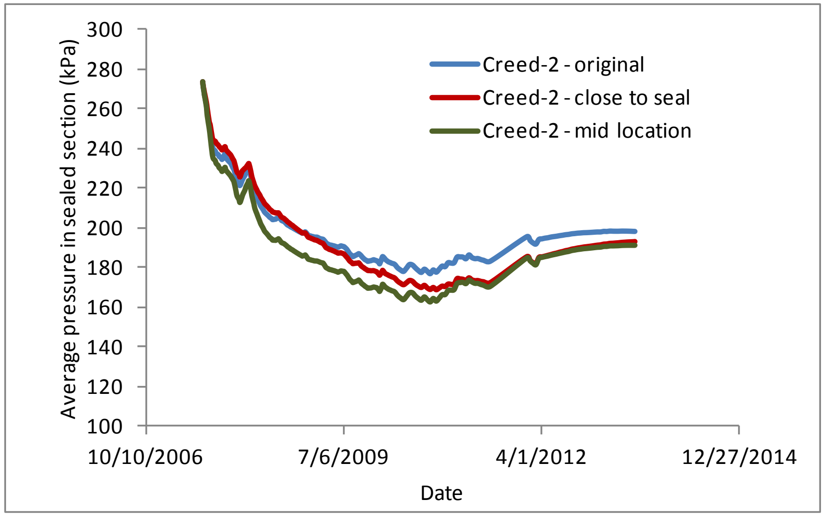
Simulated properties as of July 2013

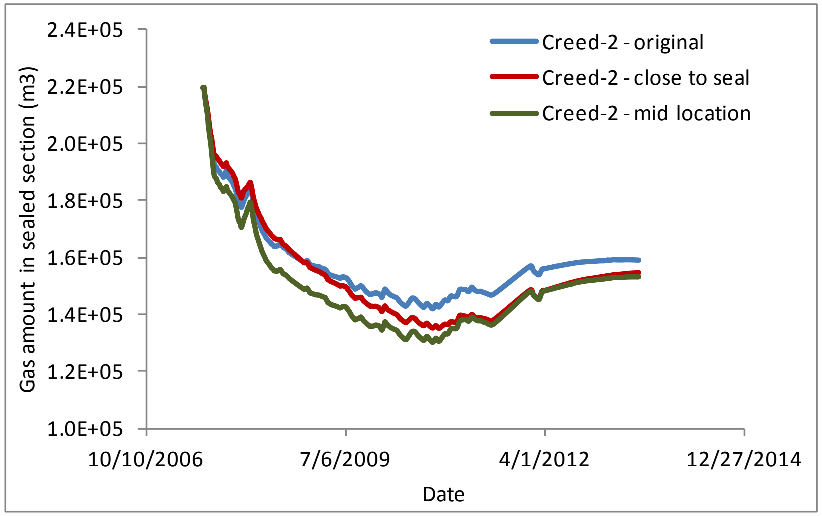
Average rate	m^3/day
Creed-2 - original	736
Creed-2 - close to seal	940
Creed-2 - mid location	826

Cumulative gas	m^3
Creed-2 - original	1.64×10^6
Creed-2 - close to seal	2.10×10^6
Creed-2 - mid location	1.85×10^6

Results

- Average pressure and methane in sealed section





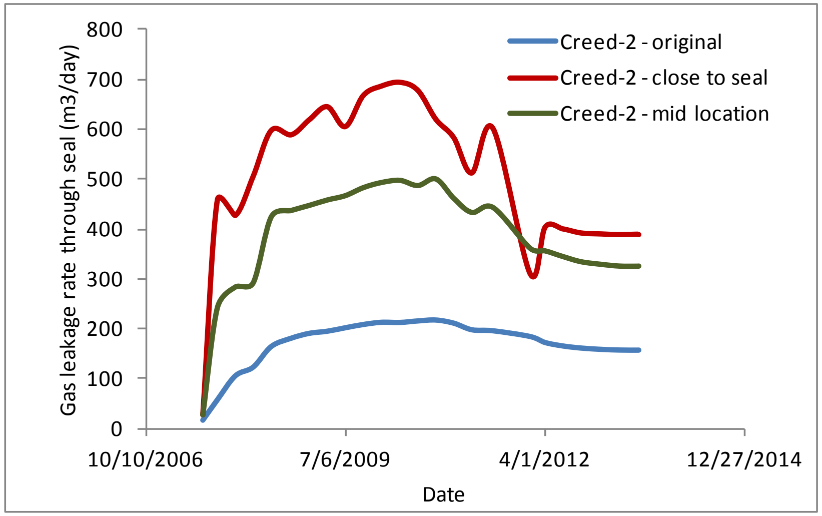
Simulated properties as of July 2013

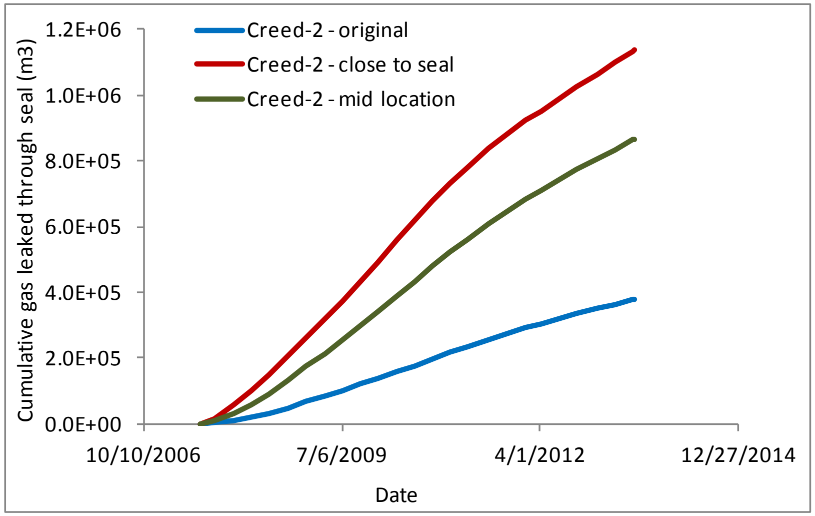
Average pressure	kPa
Creed-2 - original	201
Creed-2 - close to seal	198
Creed-2 - mid location	191

Average gas amount	m^3
Creed-2 - original	1.61×10^5
Creed-2 - close to seal	1.59×10^5
Creed-2 - mid location	1.53×10^5

Results

- Gas leakage from the seal





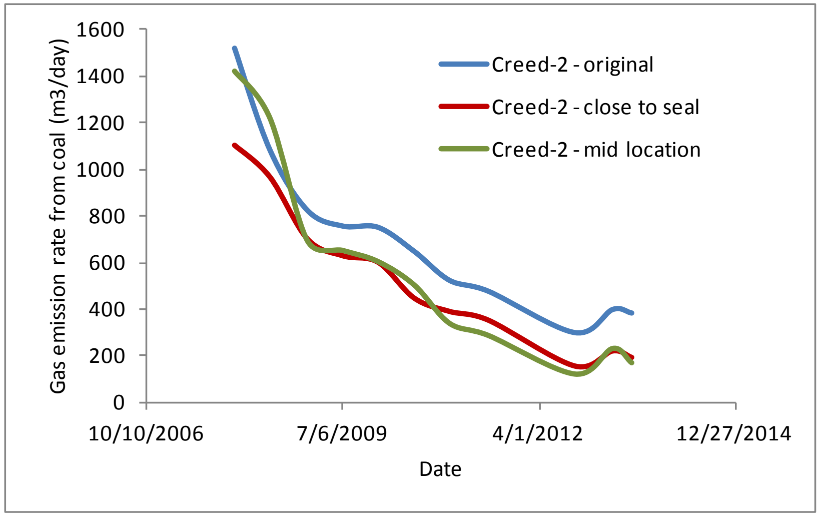
Simulated properties as of July 2013

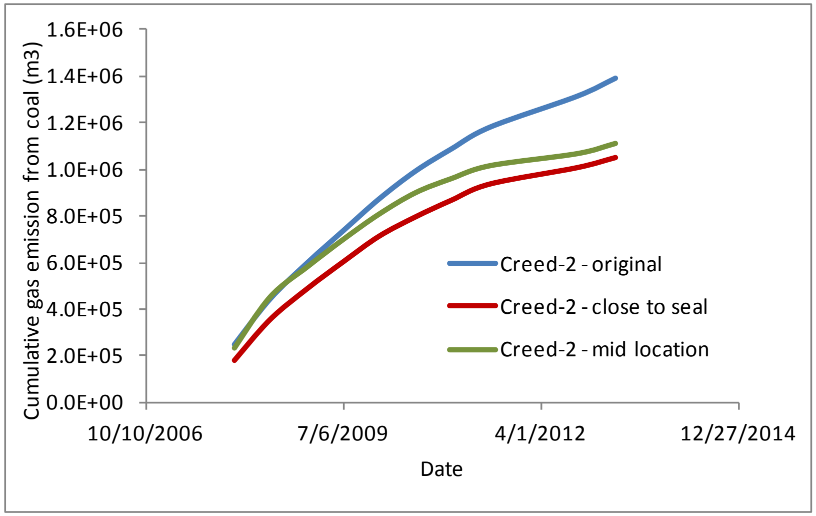
Average leakage rate	m^3/day
Creed-2 - original	168
Creed-2 - close to seal	502
Creed-2 - mid location	382

Cumulative gas leakage	m^3
Creed-2 - original	3.80×10^5
Creed-2 - close to seal	1.14×10^6
Creed-2 - mid location	8.67×10^5

Results

- Methane emission from coal into the sealed area





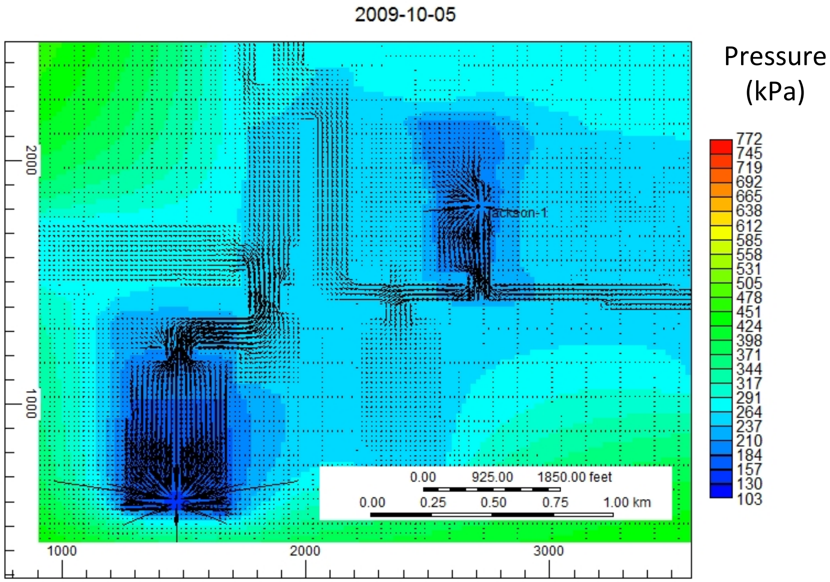
Simulated properties as of July 2013

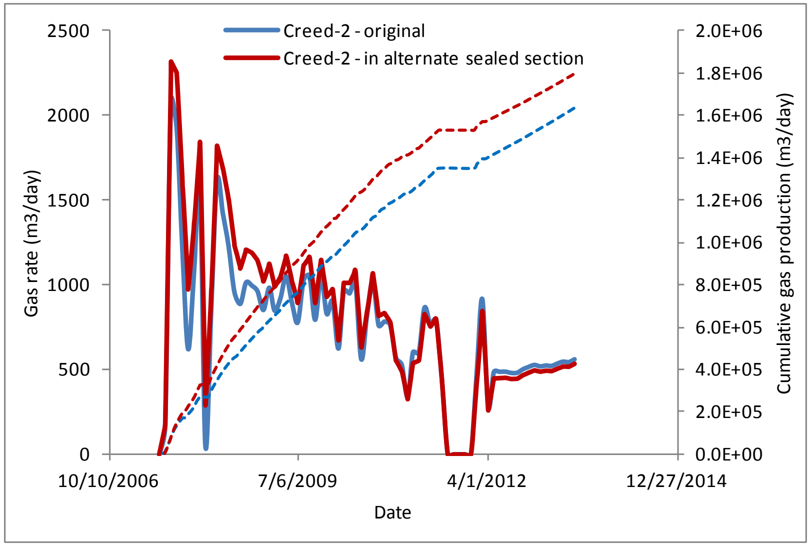
Average emission rate	m^3/day
Creed-2 - original	698
Creed-2 - close to seal	526
Creed-2 - mid location	565

Cumulative emission	m^3
Creed-2 - original	1.39×10^6
Creed-2 - close to seal	1.05×10^6
Creed-2 - mid location	1.11×10^6

Results

- An alternate sealed section





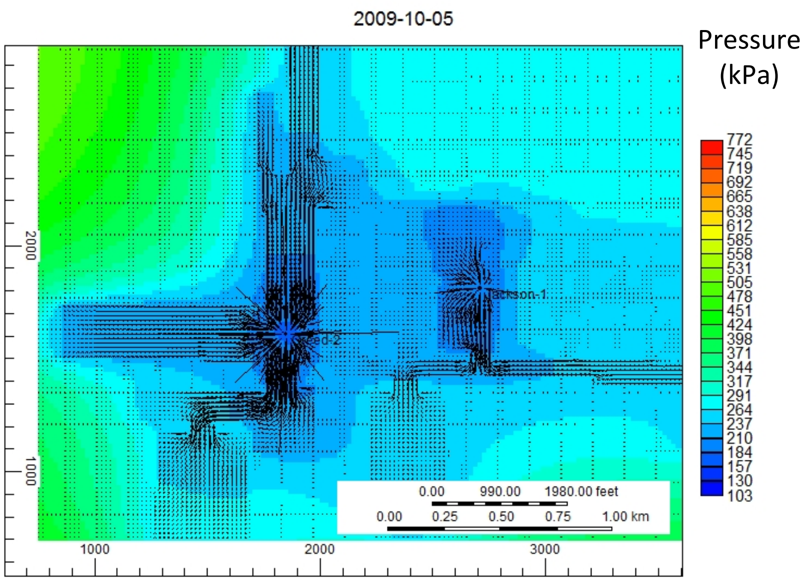
Average rate	m^3/day
Creed-2 - original	736
Creed-2 – in alternate sealed section	937

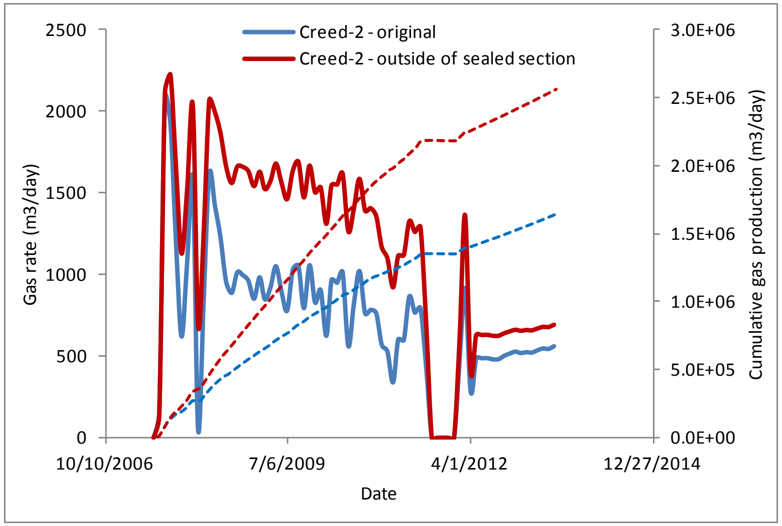
Cumulative gas	m^3
Creed-2 - original	1.64×10^6
Creed-2 – in alternate sealed section	1.79×10^6

Results

- Alternate consideration if the entire mine is sealed effectively

Creed-2 just outside of the original sealed section





Average rate	m^3/day
Creed-2 - original	736
Creed-2 – outside of sealed section	1150

Cumulative gas	m^3
Creed-2 - original	1.64×10^6
Creed-2 – outside of sealed section	2.57×10^6

Conclusions

- Methane capture from sealed mines relies on sealing efficiency of the mine and mine sections

- Modeling methane capture from abandoned mines can be challenging due to the complexity of initial conditions and mine boundaries.
  - Reservoir simulation can help
  - Mine boundaries and seals need to be defined
  - A simple composite model can help estimating mine properties as well as initial conditions.
  - Using geostatistical maps of point-wise data decreases uncertainty in important coal properties imported into the reservoir simulator.

Conclusions

- Wells drilled in larger sealed sections of the mine and away from previous workings perform better.

- Location of the well in the sealed section can be important.
    - Location close to the seam margin can have a better change of promoting more gas in-flow from coal seam
    - Location close to the seal can take advantage of leakage through the seal and higher rates
    - Knowing composition of the general mine atmosphere at multiple locations can help in deciding well location.

- Gas emission and seal leakage is important for mining safety. Simulated data can also be used in ventilation design of mines operating in the same seam.

Acknowledgements and Reference

- Drs. Maria Mastalerz and Agnieszka Drobniak of Indiana Geological Survey, and Mr. Larry Neely and Maverick Energy are gratefully acknowledged for their help in geological data and for access to well productions.
- Karacan, C. Ö. 2015. Modeling and analysis of gas capture from sealed sections of abandoned coal mines. International Journal of Coal Geology Volume 138, Pages 30–41

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